REQUEST FOR DRAWING CHANGE APPROVAL

In response to the Examiner's objection to Figs. 7 and 8 of the drawings as filed with the above-identified application on the basis that those Figures should be designated by a legend such as "PRIOR ART" because only that which is old is illustrated therein, Applicant respectfully requests approval of amendments to Figs. 7 and 8 of this application so as to designate those figures as - - PRIOR ART --. The proposed amendments to Figs. 7 and 8 are shown in red on the enclosed photocopy of the drawing sheets of this application containing Figs. 7 and 8. Further, pursuant to the Rules, Applicant is submitting herewith a clean copy of the sheet of drawing of this application that contain Figs. 7 and 8 labeled as "Replacement Sheet" in the upper right-hand margin, and respectfully requests that that clean copy of the sheet of drawing of this application containing Figs. 7 and 8 be substituted for the corresponding sheet of drawing presently on file in this application.

Applicant respectfully submits that this submission of a corrected replacement drawing sheet for the above-identified application removes one of the bases for the Examiner's currently outstanding objection to the drawings of this application. Accordingly, a decision so holding in response to this communication is respectfully requested.

REMARKS

This is in response to the Official Action currently outstanding with regard to the present application, which Official Action the Examiner has designated as being FINAL.

Claims 1, 3-13, 17 and 18 were pending in this application at the time of the issuance of the currently outstanding FINAL Official Action. By the foregoing Amendment, Applicants are herein proposing that Claims 1, 5, 6, 10, 17 and 18 be amended. Applicants are not proposing the cancellation, addition or withdrawal of any claims. Accordingly, in the event that the Examiner grants entry to the foregoing Amendment, Claims 1, 3-13 and 17-18 as amended hereinabove will constitute the Claims under active prosecution in this application.

The claims of this application are reproduced above including appropriate status identifiers and showing the Amendments proposed to be made as required by the Rules.

More particularly, in the currently outstanding Official Action the Examiner has:

1. Acknowledged Applicants' claim for foreign priority under 35 USC §119 (a)-(d) or (f), and confirmed the receipt of the required copies of the priority documents by the United States Patent and Trademark Office;

2. Objected to the drawings as filed with this application on 14 April 2004 on the grounds that Figs. 7 and 8 should be designated with a legend such as -- PRIOR ART – since only that which is old is depicted therein – **Applicants by the foregoing Request for Drawing Change Approval have presented both copies of the drawing sheets of this application that contain Figs. 7 and 8 whereon it is indicated in red that the legend -- PRIOR ART – is to be added to each of those Figures and also presented Replacement Drawing Sheets wherein the changes have been formally made.**

3. Provided Applicants with a Notice of References Cited (Form PTO-892).

4. Indicated that Applicants' previous arguments have been considered, but are deemed to be moot in view of the newly stated grounds for rejection.

5. Agreed that the cited art does not specifically teach the limitation of the equation of the pit to be less than the optical resolution capacity $\lambda/(4NA)$, but suggests that the Tominaga reference teaches one skilled in the art that a pit on a layer can achieve a higher resolution limit and that the pits can be shorter than the optical resolution limit.

6. Suggested that Applicants' comments concerning the orientation of the reading light beam are not relevant because there is no limitation concerning the same in the claims

7. Suggested that the protective layer and the substrate in the Tominaga reference are made of the same material and that one of ordinary skill in the art would attribute the functions of those layers to be the same

8. Rejected Claims 1 and 17 under 35 USC 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter that Applicants regard as the invention because the phrase "a recording layer for reproducing a signal from the pits" is indefinite because the layer does not reproduce the pits, but rather the recording apparatus or optical system converts the pits to information and thereafter compounds his misquotation of the claim language by assuming that the phraseology in question means that the recording layer is provided with pits for the reproducing apparatus to reproduce.

9. Rejected Claims 1, 3, 5-12 and 17-18 under 35 USC 102 (b) as being anticipated by the Tominaga et al 5,569,517 reference

10. Rejected Claims 4 and 13 under 35 USC 103(a) as being unpatentable over the Tominaga reference in view of Jung 5,516,568.

At the outset of these Remarks, Applicants wish to thank the Examiner and his supervisor for the courtesy accorded to their undersigned representative during a telephone interview concerning this application that was held on 18 June 2008. During the course of that interview, proposed wording for the purpose of overcoming the currently outstanding rejection under 35 USC 112 and the scope and content of the primary Tominaga, et al reference as it applies to the present invention both were discussed. Unfortunately, however, no agreement was reached with the exception that it was agreed that Applicants would file this Amendment After Final Rejection under 35 USC 1.116. In the latter regard, it was contemplated that this Amendment After Final Rejection would provide the Examiner with the opportunity to consider Applicants' positions as refined since the interview discussion and to pass upon Applicants' request that the finality of the currently outstanding Official Action be withdrawn in view of the Examiner's apparent misconstruction of the wording of Claims 1 and 17 in the currently outstanding FINAL Official Action. In addition, it was Applicants' understanding that their argument that the protective layer and the substrate in the Tominaga et al reference are clearly not made of the same material as the Examiner has suggested also would be considered by the Examiner in response to this Amendment After Final Rejection..

No further comment regarding items 1-4 and 6 above is deemed to be required in these Remarks.

With respect to the currently outstanding rejections under 35 USC 112, Applicants by the foregoing Amendment are proposing that:

(1) the reproducing layer be described in the claims as "a reproducing layer for improving the resolution of optical signals from said pits and passing said improved resolution optical signals from said pits to said optical system; and

(2) the resolution limit be described in the claims as "a resolution limit of an optical system of a reproducing apparatus which reproduces that optical data recording medium.

It is Applicants' position that these amendments remove the bases for the currently outstanding rejections under 35 USC 112 not only because it is apparent that the Examiner apparently inadvertently misunderstood the nature of the reproducing layer (as being a recording layer) when he last examined the claims of this application, but also because the function of the reproducing layer is more clearly and definitively stated in the above amended claims than heretofore. Furthermore, the nature of the optical resolution limit set forth in the claims is clarified by the foregoing Amendment. The former of these changes is believed to be straightforward and to require no further discussion herein. The latter of these changes, on the other hand, is somewhat more complex.

As the Examiner's supervisor observed during the above-mentioned interview, it is difficult to define an apparatus in terms of the characteristics of another apparatus with which it is to be used. Nevertheless, Applicants respectfully submit that the nature of the recording/reproducing apparatus that is to record information to and./or reproduce information from a particular storage medium is an important characteristic of that apparatus. Heretofore during this prosecution Applicants no believe that they may have attempted to force descriptive limitations on this characteristic of the apparatus being claimed in a manner that caused more confusion than clarity. Accordingly, in the foregoing Amendment Applicants have adopted that approach that there is going to be a reproducing apparatus that characteristically will have a resolution limit that will appropriately record information to and reproduce information from a disk having pits of a particular dimension and that that device may be characterized simply as "a reproducing apparatus which reproduces the optical data recording medium" without the necessity of more specificity. Having determined that, it then becomes straightforward to define the reproducing layer in terms of its creation and passing of signals having improved resolution over that achieved by the basic reproducing apparatus.

Hence, Applicants respectfully submit that the foregoing simplified statement of the relationship between the storage medium and the recording/reproducing apparatus with which it is used is now clear, definite and clearly indicative of the Applicants' possession of the invention at the time that this application was filed. Furthermore, once this relationship is understood in the foregoing terms, Applicants respectfully submit that there can be absolutely no question that they have satisfied the enablement and best mode requirements of the statute as well.

Accordingly, Applicants respectfully request the entry of the foregoing Amendments and the withdrawal of any and all outstanding rejections under 35 USC 112 in response to this communication.

Turning now to the Examiner's outstanding substantive rejections, Applicants already have agreed that as has been suggested the Tominaga et al. reference, in Figures 1 and 2, shows pits 21 shorter than the diameter φ_o of a reading light beam. Nevertheless, Applicants also have submitted that this is insufficient to anticipate the feature of the amended claims that specifies "pits disposed on a light incident surface thereof, corresponding to the recorded data, which are shorter than a resolution limit of an optical system of a reproducing apparatus which reproduces the optical data recording medium" for the following reasons.

The beam spot diameter in devices of the type herein claimed is generally and conventionally denoted by those skilled in the art as λ/NA (λ: being the wavelength of read light beam, and NA being the numerical aperture). In contrast, the typical optical resolution limit is generally denoted by $\lambda/(4NA)$, that is as being equal to one quarter (1/4) of the beam spot diameter. Accordingly, when one skilled in the art views the pits shown in Figures 1 and 2 of Tominaga et al. bearing the foregoing facts in mind, it clearly appears that the pits depicted by Tominaga et al are longer than the optical resolution limit referred to in the claims as discussed hereinabove. In this regard it also is to be recognized that the Tominaga et al. reference does not explicitly teach pits shorter than the resolution limit of an optical system of an associated reproducing apparatus.

Indeed, as was discussed during the above-referred to interview, the Examiner in the currently outstanding Official Action has admitted that the Tominaga reference does not teach that the pits are less than the optical resolution limit as calculated by $\lambda/(4NA)$, but nevertheless maintained that one of ordinary skill in the art would understand that Tominaga is teaching pits shorter than the normal optical resolution limit by inference from the sections at Column 2, lines 24-35 and Column 10, lines 7-20 of the Tominaga et al specification. Specifically, it is Applicants' undersigned representative's understanding that the Examiner has based the foregoing position upon an unsupported belief that the only variable that accounts for the changes in super resolution as discussed by the Tominaga et al reference is changes in pit length thereby making the presently claimed pit lengths inherent in the Tominaga et al disclosure. Applicants cannot agree.

In particular, it is Applicants' position that the Tominaga et al reference does not characterize the prior art referred to in the Background section of his specification in the manner referred to above because that art is different from and not relevant to the Tominaga Fig. 2 invention. Hence, while the materials referred to by Tominaga at Col. 2, lines 24-35 are suggested to achieve higher resolutions than the resolution limit of the associated optical system, those materials are different from the materials that Tominaga et al discusses with respect to his Fig. 2 and never quantify the length of the phase pits referred to as being optically read. Hence, Applicants respectfully submit that while Tominaga may indicate generally that reproducing layers are present in the art that can improve the resolution of information derived from pits in a substrate surface, nothing in Column 2, lines 24-35 of Tominaga is sufficient to anticipate the present invention because there is no disclosure, teaching or suggestion regarding the length of the so-called "phase pits" relative to the optical resolution limit of the optical system provided by the Tominaga et al reference in this (or indeed any) regard.

The same is respectfully submitted to be true with respect to the Examiner's comment that "super resolution is the ability to read an image beyond the diffraction limit resolution". In other words, without any specification teaching, disclosing or suggesting the specific quantitative relationship between the optical system resolution and the length of the pits, it is not possible to justify a position that the Tominaga et al reference ***anticipates the present claims that do specify the quantitative relationship not disclosed by Tominaga, et al.***

In this regard as well, Applicants respectfully submit that it should be recognized that the Tominaga et al reference specifically refers only to a ***suggestion*** that the results of at least one of the experiments described in his specification is that a higher resolution is achievable with a material that changes its reflectance with temperature. Applicants respectfully submit that the latter comment by Tominaga et al, even if true, is not sufficient to justify the expansive conclusions concerning the relationships between pit length and optical system resolution that the Examiner has chosen to draw from it. Hence, Applicants respectfully submit that neither of the portions of the Tominaga et al reference referred to by the Examiner is sufficient to constitute a reduction to practice by Tominaga, et al of the super resolution disclosed and claimed in this application and further that accordingly the Examiner has not justified a conclusion of anticipation based thereon.

Moreover, Applicant respectfully submits that Tominaga et al does not inherently teach, disclose or suggest to one skilled in the art that so-called "super resolution" technology delivers a desired performance when the length of the pits that are the signal source are at or below the optical resolution limit of the associated optical system. The Tominaga et al reference's broad and generalized suggestion that it achieves a higher resolution limit than the optical resolution limit of the associated optical system ***does not*** constitute a teaching, disclosure or suggestion that that higher resolution limit originates ***only and/or necessarily*** with signals reproduced from pits shorter than the resolution limit of the optical system.

Indeed, as will be shown below, the length of the pits from which the signal originates in so-called "super resolution" technology wherein a higher resolution limit than the resolution limit of the optical system is achieved in fact can be longer, as well as shorter, than the optical resolution limit of the associated optical system.

Hence, while the Tominaga et al reference may suggest that it obtains a higher resolution than the optical resolution of its associated optical system, that suggestion alone and taken only in and of itself ***cannot*** be taken as a disclosure that the Tominaga results are achieved with pit lengths shorter (or for that matter longer) than the optical resolution of the associated optical system. In other words, it is Applicant's position that while the broad and general overall concept of super resolution may be present to some limited extent in Tominaga et al disclosure, the Tominaga et al disclosure nevertheless is clearly totally insufficient to teach, disclose or suggest whether its results are achievable with pits that are shorter and/or longer than the optical resolution of the associated optical system because none of those quantitative measurements is contained in the Tominaga et al disclosure. Thus, the Tominaga et al disclosure is respectfully submitted to be insufficient to teach or disclose to one of ordinary skill in the art what the lengths of the pits should be in order to achieve "super resolution". In other words, the Tominaga et al specification could not qualify as a reduction to practice of the present invention because it provides no specifics concerning the length of the pits relative to the optical resolution length at all.

On the other hand, Applicants respectfully call attention to the fact that the present invention teaches unequivocally and specifically that the pit length should be shorter than the optical resolution of the associated optical system when "super resolution" is achieved.

Furthermore, as the following analysis shows, the pit length in some super resolution technologies can be longer than the optical resolution when "super resolution" is achieved thereby rendering the Examiner's "inherent teaching" basis for the currently outstanding rejections in the currently outstanding rejections untenable.

In actuality, as the mark (i.e., pit) length approaches the optical resolution limit in an ordinary optical information storage medium one cannot obtain the strength (ex. C/N) of signals reproduced from marks longer than the optical resolution limit. The technology that improves the signal strength from such marks, even if the marks are longer than the resolution limit, is sometimes described as "super resolution. See, for example, Attachment I hereto dealing with magnetically induced super resolution and the following analysis that shows that the mark (i.e., pit) lengths in the disclosed magnetically induced super resolution context are ***longer than the optical resolution limit.***

Consequently, Applicants respectfully submit that the Tominaga et al reference is insufficient to teach, disclose or suggest what the length of the pits should be in a system that achieves "super resolution" despite the Examiner's attempt to impute some sort of inherent disclosure to the Tominaga et al reference that is respectfully submitted to not really be there.

Analysis of Attachment I (magnetic super resolution) in comparison to Blu-Ray Disc of Attachment II

In support of Applicants' assertion that the pit length can be ***longer than the optical resolution of the optical system*** in some cases wherein so-called super resolution is achieved, Applicants respectfully direct attention to attachments I and II which may be identified as follows:

1. Proc. SPIE 4342,252 (2002) 50-mm CAD-MSR Disk System with Blue Laser, Y, Murakami, et al – Attachment I

2. "New Anatomy of Next –generation Optical Discs: In-depth Analysis (with partial English language translation of relevant sections) – Attachment II

The minimum mark length described in Document 1 (that describes magnetically induced super resolution) above can be calculated through a comparison with Document 2 above as follows:

The Abstract of Document 1 specifically indicates that it relates to a super resolution medium.

Document 1 at page 253, Fig. 1 explains track pitch while Document 2 illustrates the track pitch for a Blue Ray Disc

Document 1 at Table 1 on page 256 states a reproduction wavelength of 406 nm, a NA of 0.60, a recording format as land/groove and a modulation code of (1,7) RLL. Further, at page 258 of Document 1 a recording density of 11 $Gbit/in^2$ is disclosed.

Document 2, on the other hand, at page 26 indicates a recording density of 18 $Gbit/in^2$, a minimum mark length of 0.149 μm and a modulation code of 1-7PP (the same as (1,7) RLL) at 25-Gb BD.

ANALYSIS

The storage capacity, Q, for one revolution at radius r from the center of a disc is

$$Q = C \times 2\pi r/L$$

Where $2\pi r$ is the circumference, while L is the minimum mark length and ***C is a constant determined by the modulation code***. The area S of the data recording region located at radius r is given by

$$S = 2\pi r \times P$$

Where P is the recording pitch.

Hence, the recording density D for the revolution is given by

$D = Q/S = C \times 2\pi r/L/(2\pi r \times P) = C/(L \times P)$

Assuming the density D1 is the minimum recording density, the minimum mark (i.e., pit) length is L1, the recording pitch is P1 and the constant C1 is associated with document 1, while with regard to the structure of document 2 the density D2, the minimum mark length is L2, the recording pitch is P2 and the constant is C2

$D1 = C1/(L1 \times P1)$ and $D2 = C2/(L2 \times P2)$

<u>The modulation codes for Document 1 and Document 2 are equal which means that:</u>

<u>C1 = C2</u>

Thus, when one substitutes the values from documents 1 and 2 into the foregoing:

D1 = 11 Gbits/in^2 (page 258 of Document 1)

P1 = 0.40μm – Since the recording scheme attached to document 2 is 'groove recording" (see Table 1) Recording Pitch P2 = Groove Width + Land Width. In contrast, the recording scheme of document 1 is "land/groove recording (see Table 1) and Recording Pitch P1 = groove Width = Land Width.

Then:

For the structure of Document 2

$D2 = 18$ Gbits/in^2

$P2 = 0.32$ μm

$L2 = 0.149$ μm (see Table 1)

Accordingly:

Since $C1 = C2$

$L1 = C1/(D1 \times P1) = D2 \times (L2 \times P2)/(D1 \times P1) = 0.195$ μm (well in excess of the minimum mark length $L2 = 0.149$ μm

Clearly, therefore, if both the discs of Document 1 and Document 2 are read by the same optical system and L1 is equal to the minimum optical resolution of the optical system, the disk of Document 2 has a minimum mark length in excess of the optical resolution of that optical system, yet both the discs of Document 1 and Document 2 can in appropriate contexts exhibit super resolution behaviors.

Note: The recording scheme attached to document 2 is 'groove recording" (see Table 1) Recording Pitch P2 = Groove Width + Land Width. In contrast, the recording scheme of document 1 is "land/groove recording (see Table 1) and Recording Pitch P1 = groove Width = Land Width

In contrast to the foregoing, the present specification, at page 39, last paragraph to page 40, paragraph. 3, clearly describes the use of pits < 0.14 μm, that is shorter than the optical resolution limit, in securing sufficient signal quality (optical resolution limit: 0.16 μm = 408 nm / (4 x 0.65). In particular support of this assertion, please see the present specification at page 39, paragraph. 2.

Accordingly, Applicants respectfully submit that the Examiner's rejection of the present application as being anticipated by the Tominaga et al reference is misplaced and should be withdrawn in response to this communication. A decision so holding is respectfully requested.

Moreover, Applicants have noted that in comparing Claim 1 of the present application with the Tominaga et al reference, the Examiner has asserted that the protective layer 10 of Tominaga et al. corresponds to the substrate of claim 1. See the currently outstanding Official Action at page 3 in the paragraph starting with "Regarding Claim 1. It is to be noted in this regard, however, that Tominaga et al. includes a substrate 2 separately from the protective layer 10. Applicants respectfully submit in this regard that it is the substrate 2 that the Examiner should regard as corresponding to the substrate of claim 1 in his comparisons of the present claims with the Tominaga et al reference and that when the correct comparison is made in view of the foregoing discussion it is apparent that this application is neither anticipated nor unpatenatably obvious over the art currently relied upon by the Examiner.

In the latter regard, Applicants respectfully submit that in the field of the optical data recording mediums it is so well known as to require no further support in these Remarks that what is termed as being a "substrate" is clearly distinct from what is termed as "protective layer".

Therefore, Applicants respectfully submit that it will be seen that the Examiner continues to characterize both the elements 10 and 21 of FIG. 2 of the Tominaga reference relied upon as being " a substrate having pits". However, the substrate is clearly indicated at 2 and the pits are clearly indicated at 21 (see Tominaga at Column 4, lines 18-22). Further, there is no indication that irregularities depicted in the drawings on the inwardly facing surface of the protective layer 10 in any way are (or can be) used to store information in a manner analogous to that utilized with respect to the pits. Still further, contrary to the Examiner's assertion, it appears that while the substrate 2 and the protective layer 10 are to be formed of less heat resistant resins than the mask layer 32 and can be deformed (see Tominaga et al at Column 7, lines 44-47), ***the substrate and the protective layer are not disclosed as being formed of the same material as the Examiner has suggested in the currently outstanding Official Action.***.

In summary, therefore, Applicants respectfully submit that the foregoing Amendments, if granted entry by the Examiner, overcome the currently outstanding rejections under 35 USC 112 and therefore at least place those claims in better condition for Appeal if not in condition for allowance as required by 37 CFR 1.116. Also, Applicants respectfully submit that upon reconsideration in view of the foregoing Amendment and Remarks the Examiner will realize that while the Tominaga et al reference upon which he has relied may be generally relevant to the presently claimed invention, it is simply insufficient to justify the anticipatory conclusions that he has seen fit to derive from it.

Hence, for each and all of the foregoing reasons, entry of the foregoing Amendment, withdrawal of the currently outstanding FINAL rejection, reconsideration and allowance of all of the claims present in this application after the entry of this Amendment in response to this communication are respectfully requested.

Applicant also believes that additional fees beyond those submitted herewith are not required in connection with the consideration of this response to the currently outstanding Official Action. However, if for any reason a fee is required, a fee paid is inadequate or credit is owed for any excess fee paid, you are hereby authorized and requested to charge and/or credit Deposit Account No. 04-1105, as necessary, for the correct payment of all fees which may be due in connection with the filing and consideration of this communication.

Respectfully submitted,

Date: 3 July 2008

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SIGNATURE OF PRACTITIONER

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Document 1.

50-mm CAD-MSR Disk System with Blue Laser

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ABSTRACT

A mobile magneto-optical disk system with 2 Gbytes user-capacity is proposed. The disk consists of a center aperture detection type of magnetically induced super-resolution medium, a 0.5 mm thickness substrate with 50 mm in diameter, and a newly developed ultraviolet curing resin film to keep the disk tilt small even if its surrounding environmental condition changes. The optics contains a blue laser diode of a 406 nm wavelength and an objective lens with a numerical aperture of 0.6. A laser pulsed magnetic field modulation method is employed and it realizes land and groove recording with an effective track pitch of 0.40 μm. Practicable system margin values are confirmed at 0.146 μm bit density (11 Gbits/in^2 areal density.)

Keywords: Magneto-optical disk, center aperture detection, magnetically induced super resolution, land and groove recording, laser pulsed magnetic field modulation

1. INTRODUCTION

A center aperture detection type of magnetically induced super-resolution (CAD-MSR) medium for red laser optics had been studied[1-3], and it had already been in commercial use as like ID-photo[4]. In order to obtain more huge capacity, CAD-MSR media had been modified to be suitable for blue laser recording[5,6]. The combination of CAD-MSR media and blue laser optics enabled us to realize an acceptable capacity disk system for mobile audio-visual applications.

This paper describes a 2 Gbytes user-capacity disk system with a 50 mm diameter CAD-MSR disk. Firstly, key technologies in this study are introduced. Secondly, the 0.5 mm thickness disk properties are reported. Realizing the 0.5 mm thickness disk was one of key issues in this study. We utilized an amorphous polyolefin polymer as the substrate material and developed a novel ultraviolet curing (UV) resin material for a protective film formed on the CAD-MSR medium. The completed disk, consisted of the injection molding substrate with a 0.5 mm thickness, the CAD-MSR medium, and the newly developed UV resin protective film, showed very small disk tilt and it was kept even in severe environmental tests. Finally, experimental results for readout and recording characteristics are reported. The obtained margin values proofed that the proposed system was available for practical use.

2. KEY TECHNOLOGIES

Key technologies in this study are illustrated in Fig. 1. It is our proposal to realize a mobile consumer use product with acceptable wide system margins. A blue laser diode made by Nichia Corporation was used in this study. The wavelength was 406 nm. A moderate 0.6 numerical aperture (NA) objective lens was utilized as like conventional far field optics. The substrate dimensions were 50 mm in diameter and 0.5 mm in thick. The latter induced relatively larger tilt tolerances in comparison with the thicker substrate. The substrate was fabricated by an injection molding process. The effective track pitch was 0.4 μm and its depth was 35 nm. The groove depth was set to obtain good margin balance between lands and grooves. Such dimensions of grooves were duplicated through a reactive ion etching (RIE) glass mastering process. It brought a good bit error rate (BER) of magneto optical (MO) signal. An improved CAD-MSR medium for blue laser recording was supplied to this study[7]. It was a magneto-static type of CAD-MSR medium and it had higher recording

Optical Data Storage 2001, Terril Hurst, Seiji Kobayashi, Editors,
Proceedings of SPIE Vol. 4342 (2002) © 2002 SPIE · 0277-786X/02/$15.00

power sensitivity and higher recording magnetic field sensitivity suitable for mobile drives with lower electric consumption. A newly developed UV resin protective film was employed to reduce the transient disk tilt even if the surrounding environment c hanges. It is one of the most important technologies because it enabled the 0.5 mm thickness disk to be in practical use, and our proposal system was realized. A laser pulsed magnetic field modulation method was adopted in this system and it enabled for us to achieve land and groove recording with a narrow 0.4 µm track pitch. By combining those components, available system margins were obtained at an areal density of 11 Gbits/in^2.

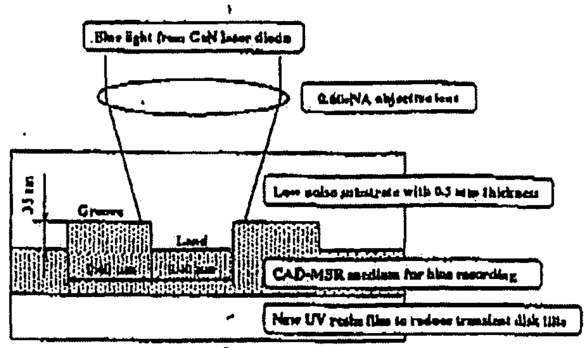

Figure 1: Key technologies in this study.

3. FABRICATION OF 0.5 MM THICKNESS SUBSTRATE

3.1 RIE glass mastering

An RIE glass mastering technique was adopted in this study[*]. Figure 2 shows the farmer part of disk fabrication processes. A positive type photo resist was spin-coated on a quartz glass substrate. The typical thickness of resist was 70 nm to obtain the groove depth of 35-40 nm. Laser cutting (exposure) process was carried out and the exposed resist was removed by developing. Generally this remaining resist pattern is utilized as a photo resist master to fabricate a stamper for the injection molding. In this study the quartz glass was reactive-ion-etched with CF4 gas, and the etched grooves were formed directly on the glass surface. In detail, the photo resist pattern was also etched with a similar etching rate, and the remaining photo resist was removed after etching.

Figure 3 shows an atomic force microscope (AFM) image of the RIE glass master. The etching power was 400 watts. The centerline average roughness of etched groove surface was less than 0.2 nm. It was a quite small value as well as the quartz glass surface or the land surface. The land portion was not etched because it was covered by the photo resist. Additionally in the RIE process, the land width of the RIE glass mater hardly depend on that of the covered photo resist pattern. It only depends on the dimensions near the bottom of the photo resist pattern. This advantage produced better uniformity of land (and groove) dimensions. Figure 3 shows it clearly that the boundary wall between the land and groove has a very smooth surface and a good straightness in tangential direction. Such the superior flatness and the good uniformity of land and groove dimensions including groove walls totally induced a lower track noise than that of the fabricated disk by a photo resist master. The lower track noise led the good BER of MO signal, and brought wide system margins.

The RIE glass master has the other advantage for the mass production of substrate. One RIE glass master can produce multiple stampers. In general, the stamper for the injection molding is fabricated by electroforming a photo resist master. In this case, the photo resist pattern on a glass substrate is damaged when the stamper is peeled off the photo resist master

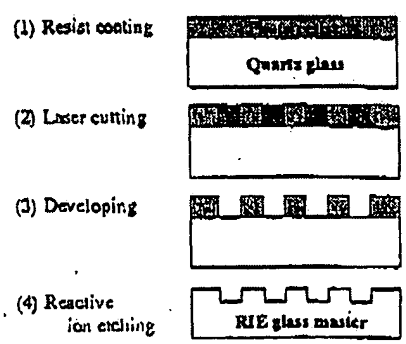

Figure 2: Disk fabrication processes.

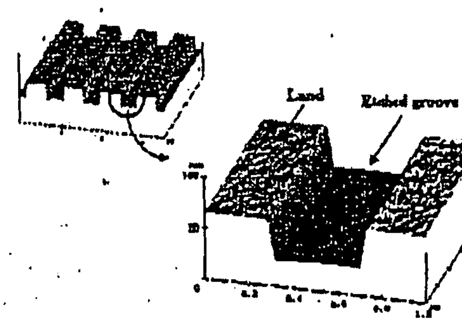

Figure 3: Atomic microscope image of reactive ion etched glass master.

after the electroforming process. Therefore, only one stamper can be obtained from one photo resist master. On the other hand the etched pattern sustains no damages. So multiple stampers can be obtained from one RIE glass master with good reproducibility. It is useful to product a large quantity of substrates with the same quality.

3.2 Injection molding

Desirable key functions for substrates in the MO field are: small birefringence, small tilt, and good duplicate ability. To meet these demands, an amorphous polyolefin polymer was employed as the substrate material in this study. It had better optical characteristics than a conventional polycarbonate polymer and had no difficulty in controlling the disk tilt and the duplicate properties of grooves in our injection molding process.

Figure 4 shows the birefringence of injection molded substrates of the amorphous polyolefin and the polycarbonate. The vertical axis indicates the retardation value for a single pass of a 633 nm wavelength light irradiated in normal direction to the substrate surface. A retardation value less than ±20 nm is preferable in practical use. The amorphous polyolefin met the demand in all radial positions. The polycarbonate showed large retardations at the inner radius area in our study.

Figure 5 reveals a typical data of axial deflection on the injection molding substrate. The maximum axial deflection was below 14 μm per revolution, and the radial and tangential tilts were +1.2 mrad. and +0.6 mrad., respectively. Those tilts are small enough for practical use. Additionally, the deviations of tilts between several hundred substrates were within 0.2 mrad. in both directions. A good reproducibility of tilts in the injection molding process was confirmed.

By the way, we should make a completed disk tilt be in a desirable value. The completed disk contains a CAD-MSR medium and a UV resin protective film formed on the substrate in this order. The radial tilt moves generally by forming a recording medium and a UV resin protective film, due to the unbalance of internal stresses. In our study, the movement was approximately −2 mrad. and the radial tilt of completed disk in this case was about −1 mrad. The tangential tilt was kept almost the same value of the substrate. Both radial and tangential tilts on the completed disk tilts are small enough for practical use. Our internal targets for the completed disk tilts were ±3.5 mrad. in radial, and ±2.5 mrad. in tangential direction. The fabricated disk in this study met the internal specifications with sufficiently wide production margins.

Figure 6 shows an AFM image of the injection molding substrate. The image indicates the good straightness of boundaries between lands and grooves, as well as the RIE glass master shown in Fig. 4. And also the centerline average roughness was less than 0.2 nm on both land and groove surfaces. The roughness was almost the same as those on the RIE glass master and the stamper. Thus we confirmed that the amorphous polyolefin revealed a good duplicate ability and generated a smooth surface in the injection molding process.

3.3 New UV resin material to reduce transient disk tilts

It is one of the most significant matters to keep a completed disk tilts constant whenever the surrounding environmental conditions change. We developed a new UV resin film and confirmed its ability for reducing the transient tilts[7].

In general, when the surrounding temperature or the humidity changes, a disk tilt changes by the difference of thermal or humidity expansion or contraction volumes between the substrate, the recording film, and the UV resin film. Conversely, it is possible to reduce the tilt movement by adjusting expansion (or contraction) volumes between them. In the case of the temperature expansion, the coefficient of thermal expansion of the CAD-MSR film is approximately one order less than

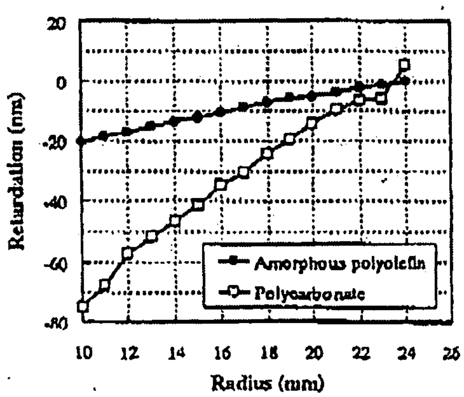

Figure 4: Birefringence of injection molding substrates.

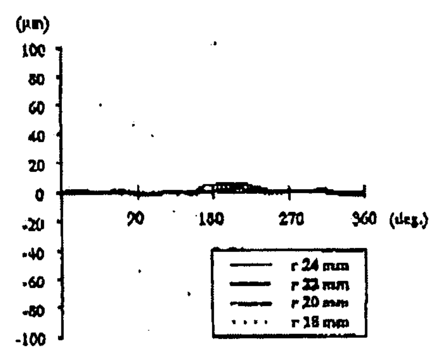

Figure 5: Axial deflection of injection molding substrate with 0.5 m m thickness.

hose of the substrate and the UV resin materials. Moreover, the humidity expansion of the CAD-MSR is supposed to be almost zero and can be negligible compared with other elements. So we modified the UV resin material to be balanced the thermal and humidity expansion volumes between the substrate and the UV resin film. In concrete, the UV resin material was modified to have a larger thermal expansion coefficient and a smaller humidity expansion coefficient than those of commercially used UV resin materials. Off course, the modified UV resin maintained other important roles: protection of recording layers and high lubrication ability for the magnetic head.

Figure 7 shows an experimental result for an environment test to confirm the new UV resin performance. The experimental disk consisted of: an amorphous polyolefin substrate with a 0.5 mm thickness, a CAD-MSR medium with about 200 nm total thickness, and a newly developed UV resin protective film with a 15 μm thickness. The horizontal axis indicates the exposure time and the sample disk had been placed in the environmental testing chamber. A laser displacement meter for measuring the sample disk tilt was also constructed in the testing chamber and the disk tilt was measured in real time. The vertical axis shows the radial tilt value. The minus tilt on the vertical axis indicates that the disk gets close to an optical head. The tilt change in tangential direction was very small within 0.3 mrad. in this test. So the tangential data were omitted graphing.

In this test, the sample disk had been placed in the testing chamber over 24 hours under a condition of 25°C-50%R.H. (relative humidity) to let the disk tilt reach to an equilibrium state. The 25°C-50%R.H. condition is very close to the room condition, so we defined the tilt value of the above equilibrium state as the completed disk tilt. The completed disk tilt in this test was +1 mrad. as shown in the figure. After confirming the completed disk tilt, the environmental condition was changed to 70°C-5%R.H. The 5%R.H. at 70°C had an important meaning that the absolute humidity, not relative humidity, was almost the same as the 50%R.H. at 25°C. So we could know the tilt change only by the temperature transition. It was only +0.7 mrad. Then the environmental condition was returned to 25 °C-50%R.H., and we confirmed the disk tilt also turned back to the initial value. Then only the humidity was changed from 50 to 90%R.H. at 25 °C. The tilt change only by the humidity transition was −1.6 mrad. The latter humidity change looked like large, but the absolute tilt value was in the range between +2.1 and −0.2 mrad. It was quite small value for reading/writing operations. And we should point out that: in the case of utilizing a commercially used UV resin material, the radial tilt exceeded 10 mrad. in our study.

Figure 8 shows the other result for a more severe testing condition. The test condition was compliant with internally defined operating conditions. The temperature range was −5 to 65°C and the humidity one was nearly 0 to 90%. In this test, the largest tilt change was about −2 mrad. at the condition change from 25°C-50%R.H. to 38°C-90%R.H. It was slight larger than the previous data shown in Fig. 7. It is caused that not only humidity change but also temperature change was added in this test. The humidity absorption became larger due to the higher temperature, we suppose. Nevertheless, the absolute radial tilt was sufficiently small and within 1.2 mrad.

In this test, we tried testing under the lower temperature condition than -5°C. However a condensation occurred and it prevented measuring the disk tilt. With making an estimate from the tilt shift result between 25 and -5°C, the predicted tilt at -25°C becomes −1.17 mrad. If the -25°C condition was adopted, the disk tilt would be kept in practicable range. In addition, the sample disk showed a good reversibility of tilt in other climatic environment tests: 80°C-90%R.H. for 240 hours and -25°C for 240 hours. It proofs that both materials of the UV resin and the substrate maintained their original characteristics even after such tight conditions.

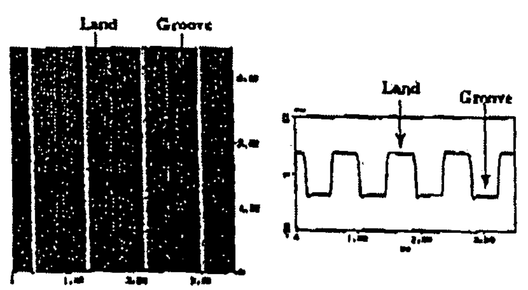

Figure 6: Atomic microscope image of injection molding substrate.

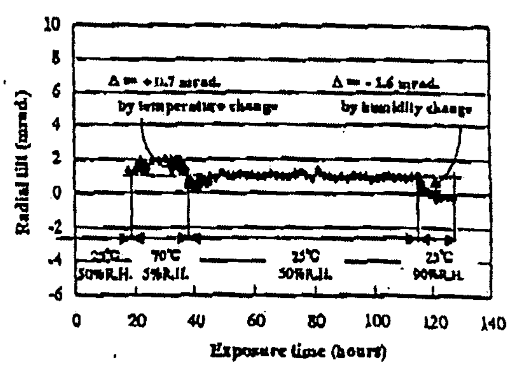

Figure 7: Disk tilt change in fundamental environment test.

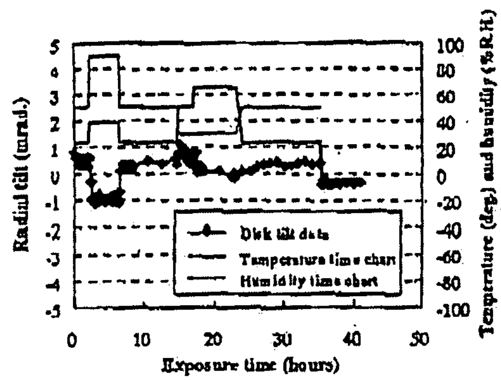

Figure 8: Disk tilt change in internally defined environment test.

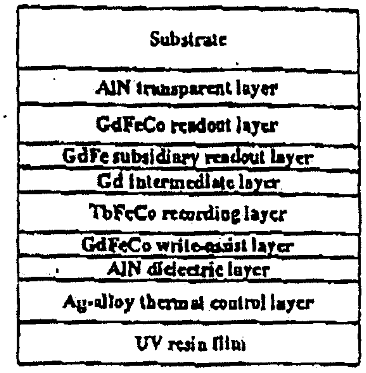

Figure 9: CAD-MSR medium structure in this study.

4. READOUT AND RECORDING PROPERTIES

Figure 9 shows the CAD-MSR medium structure in this study[7]. The major improvement points compared with that in the previous report[5,6] were as follows: A Gd intermediate layer was employed instead of a conventional non-magnetic layer made of Ag-alloy, and the tri-layer structured recording layers was changed to a single recording layer and added a write-assist layer. The former made the readout power margin wider and the latter made the recording power and magnetic field sensitivity higher.

Table 1 presents measurement conditions. The effective track pitch was 0.4 μm and land and recording was performed in this study. The recorded bit length for various system margin estimations was set to 0.146 μm. The areal bit density was 11 Gbits/in^2. The laser pulsed magnetic field modulation method was employed to realize higher track density recording and the recording pulse duty was set to 33%. The linear velocity was 3.2 m/s, and the recording magnetic field was 250 Oe. The data channel clock was 33 MHz and the (1,7) RLL (run-length-limited) coding was utilized. The partial response (PR) of (1,2,1) detection and the Viterbi detection methods were combined to evaluate the BER.

Figure 10 shows the BER dependence on the linear bit length. The recording channel clock was kept constant and the linear velocity was changed for each bit density in this measurement. The BER values on both land and groove were in constant over the bit length of 0.16 μm, and those values were near 1E-6. The BER value near 1E-6 indicates that the number of defects on the substrate is quite small, and the readout resolution of medium is sufficiently high. Our target bit density in this study was 0.146 μm length. A slight less of BER was observed but it was a relatively good BER value. Several system margins were investigated in the bit density.

Figure 11 shows the BER dependence on the recording laser power. We defined a recording power margin from this result. The readout power was 1.82 mW for land and 1.68 mW for groove. Both of those powers were the center readout power

Table 1 Measurement conditions.

Wavelength	406 nm
NA	0.60
Substrate thickness	0.5 mm
Effective track pitch	0.40 μm (L/G recording)
Recording bit length	0.146 μm
Recording method	Laser pulsed MFM
Recording pulse duty	33%
Linear velocity	3.2 m/s
Recording magnetic field	250 Oe
Channel clock	33 MHz
Modulation code	(1,7) RLL
Data detection	PR(1,2,1) + Viterbi

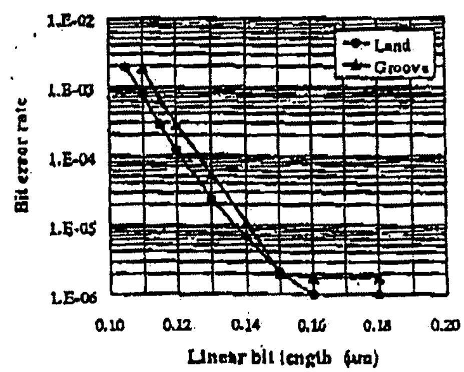

Figure 10: Bit error rate dependence on linear bit length.

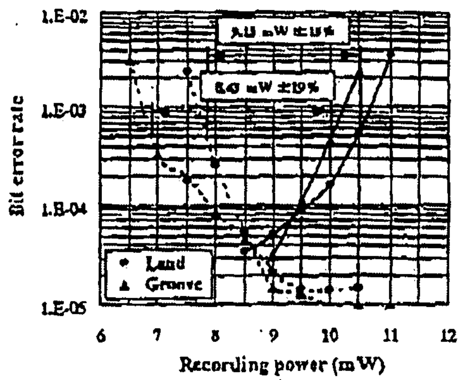

Figure 11: Bit error rate dependence on recording laser power.

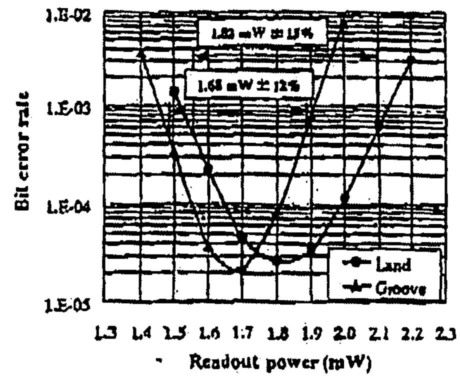

Figure 12: Bit error rate dependence on readout laser power.

obtained in a readout power margin measurement. The dotted lines show the BER for a 1-track recording state. The measured track had been pre-recorded with a large recording power above 10 mW, and after that the track was over-written with a small power. So residual domains exists if the overwrite power is too small. It was a severe condition to know the overwrite-ability. The adjacent tracks were in an as-deposition state, where no data was recorded. The solid lines show the BER for a 3-track recording state. The adjacent tracks were also recorded with the same recording power. The inserted numbers in the figure indicate recording power margins for land and groove. The BER criterion for determining the margin was 5E-4. It was equivalent to the limit of error correction ability in this study. The under limit of recording power was 7-8 mW. It was nearly equal as that in red laser systems we had been studied. It is acceptable recording power sensitivity for realizing a mobile disk drive system. The upper recording power was limited by the cross-write phenomenon dominantly, not by the cross-talk one. In blue laser recording, the peak temperature of the recording medium reaches higher than that of the red laser recording due to the higher energy density in the beam spot. Therefore, to let the heat out from the recording layer became more important and the CAD-MSR medium in this study had the countermeasure by increasing the thickness of thermal control layer. The thickness was changed from 40 to 70 nm in this study. It functioned effectively to reduce cross-write and a relatively large margin value was obtained as shown in Fig. 11. The internal specification for the recording power margin was ±15%. The experimental results were beyond it both land and groove. In the case of the 40 nm thickness, the margins were less than ±10%.

Figure 12 shows the BER dependence on the readout laser power. The measured track was the 3-track state recorded with the center recording power. The obtained margins were clear our internal specification of ±12% on both land and groove. Figure 13 shows disk tilt margins in: (a) radial, and (b) tangential directions, respectively. The measured track was the same 3-track state for estimating the readout power margin. In this measurement, the readout power was adjusted for each

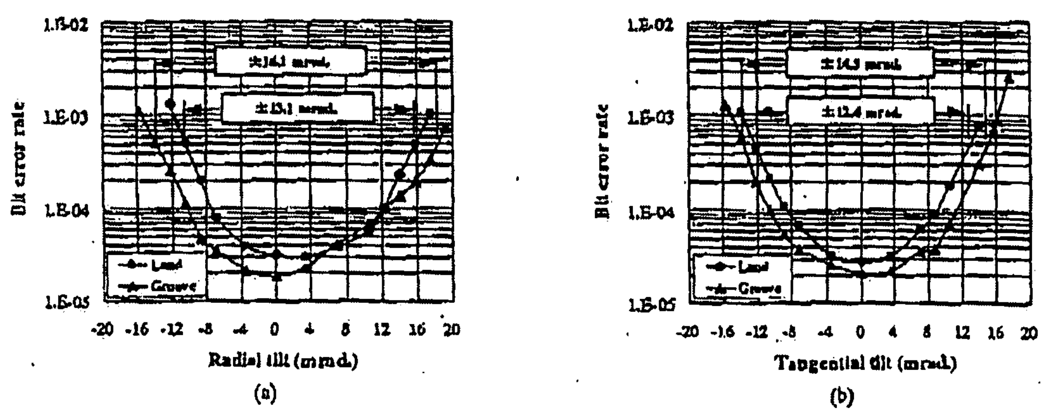

Figure 13: Bit error rate dependence on: (a) radial, and (b) tangential tilt.

tilt state. In the CAD-MSR system, controlling the aperture size is important to get wider tolerances for readout. When the disk tilts, the peak intensity of the focused readout beam decreases by coma aberration in comparison with that in the no-tilt state. In order to compensate the intensity loss and to get the same aperture size, a higher readout laser power is needed. Consequently, the larger the tilt, the larger the readout power becomes. The internal specifications were ±10 mrad. for radial and ±6 mrad. for tangential directions. The obtained margins were large enough compared with the specifications. It is noted that such wide enough margins were generated by combining of the moderate 0.6 NA lens, the thin 0.5 mm substrate, and the CAD-MSR medium.

Table 2 lists experimental results and internal specifications for each item. The readout power margin for the groove and the recording power margin for the land were very close to the internal specifications but all of experimental results satisfied the specifications. Additionally, the radial and tangential tilt margins were sufficiently wider than the specifications. It suggests that the 0.5 mm thickness disk can be applied to higher numerical aperture systems as like 0.65 or 0.7. Realizing larger capacity disk system is to be expected.

Table 2 Margin list of experimental results and internal specifications.

	Experimental results	Int. spec.
Readout power	Land 1.82 mW ±15% Groove 1.68 mW ±12%	> ±12%
Recording power	Land 8.15 mW ±15% Groove 8.43 mW ±18%	> ±15%
Radial tilt	Land ±13.1 mrad. Groove ±18.1 mrad.	> ±10 mrad.
Tangential tilt	Land ±12.4 mrad. Groove ±14.5 mrad.	> ±6 mrad.
Total disk tilt (A+B) (radial direction)	< ±3.22 mrad.	< ±5.25 mrad.
A: Fabricated disk tilt	< ±2.00 mrad.	< ±3.50 mrad.
B: Change in environment tests	< ±1.22 mrad.	< ±1.75 mrad.

5. CONCLUSIONS

We confirmed that a 2 GB user-capacity CAD-MSR disk with a 50 mm diameter was accomplished with practicably available margins. The experimental optical head consisted of a blue laser diode and an objective lens of 0.6 NA. The areal recording density reached to 11 Gbits/in^2 with land and groove recording of 0.4 μm wide tracks. The disk substrate thickness was 0.5 mm. We confirmed the injection molding of the 0.5 mm substrate was possible with small tilt, good duplicative ability, and good optical properties. We also developed a novel UV resin material to keep the completed disk tilt small even if the surrounding climatic condition changed. The CAD-MSR medium was improved to match blue recording and it generated superior readout resolution and good sensitivities for the recording laser power and the recording magnetic field. The accomplished CAD-MSR disk produced available system margins for practical use.

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Document 2.

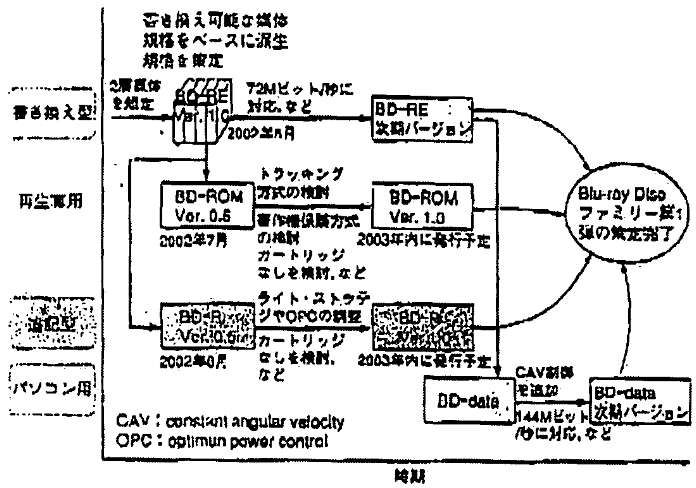

図4　2003年内を目標に再生専用と追記型の媒体規格を策定
Blu-ray Disc規格のうち，策定を終えたのは書き換え可能な媒体の規格である。現在，再生専用媒体や追記型媒体などの規格を策定中で，2003年内にも規格書を発行する予定だ。このほか，パソコン用途も検討中だ。

いうことだけではなく，ユーザーの心をグッと引き付けるような新機能の導入が不可欠だと考えたからである。VHS方式の磁気テープからDVD-Videoディスクに移行する際にもDVDメニューに代表される対話型の操作など，新機能の導入がひと役買っている。

BD-ROMは現在，米国映画業界などからの要望を反映する形で規格策定作業を進めている。規格は完全には固まっていないが，DVDを超える対話型操作や，ブロードバンド回線を利用したインターネット・サービスとの連動機能などを盛り込む予定である。

再生専用/追記型規格は2003年内に

Blu-ray Discの規格を拡張していくに当たり我々は，書き換え可能な媒体規格「BD-RE Ver. 1.0」をベースに後続規格を派生させる「Transfer all features」の思想を貫く[注3]。例えばディスク片面単層の記録容量は，BD-RE Ver. 1.0で固めた23.3Gバイト，25Gバイト，27Gバイトを堅持する。データ転送速度も36Mビット/秒を標準値とし，今後のすべての規格を定めていく計画である（図4）。

BD-ROMとBD-Rについては，2003年内に「BD-ROM Ver. 1.0」「BD-R Ver. 1.0」として規格化する予定である[注4]。この際に物理層も拡張する。例えばBD-ROMではトラッキング方式を追加する。BD-REで採ったPP (push-pull) 方式†に加えて，再生専用ディスクのピット列を追跡するのに優れたDPD (differential phase detection) 方式†を加える方向だ。BD-REで採用したカートリッジも不要とする予定である。

BD-Rでは，ライト・ストラテジ†やOPC (optimum power control) †のパラメータなどを追媒体の記録膜に向けて修正する。カートリッジも不要とし，当初から2倍速（72Mビット/秒）記録を盛り込む予定だ。片面2層ディスクの規格化も検討している。

BD-RE規格もVer. 1.0からの拡張を進める。次期バージョンではまず，BD-Rと同じく2倍速記録の導入を計画している。

BD-RE規格は光ディスク録画機などのAV機器を主なターゲットにしているが，実はパソコン用の記録媒体として使える仕組みも既に盛り込んである。現在のところ，新たにパソコン用規格「BD-data」を策定するかは未定だが，拡張は容易だ。高速記録が重視されるパソコン用途では，早期に4倍速（144Mビット/秒）への対応が進むことになるだろう[注5]。このときにはディスクの回転制御方式を現行のBD-RE規格のCLV (constant linear velocity) からCAV (constant angular velocity) に変更する必要があると考えている。

BD-RE，BD-ROM，BD-R，BD-dataなどの拡張によって，第1世代のBlu-ray Discファミリー規格が完成することになる[注6]。このほかに小径媒体などの実用化も視野に入れている。例えば，CDやDVDのような直径8cmの媒体に格納できる容量を計算すると，ディスク片面単層で約7.5Gバイト。直径12cmの片面単層DVDディスクの1.5倍に当たるデータを格納できる。

注3）Blu-ray Disc規格を策定するに当たっては，同規格のベースとなっているBD-RE規格を策定した中核技術者が，必ずBD-ROM規格やBD-R規格を検討する会議にも出ることにしている。こうすることで常にBD-RE規格を受け継いだ一貫性のある派生規格にしていくことを狙っている。

注4）物理層だけではなく，ファイル・システム層やアプリケーション層までを規定した完全版を発行する。

†PP (push-pull) 方式＝トラッキング・エラー信号を得る手法の1つ。ディスクの記録面で反射・回折した光を，トラックを中心線として対称に配置した2つの光検出器でとらえる。そして2つの検出器で受けた光量の差を検出し，左右へのズレ量を得る。1本のレーザ・ビームで信号を検出できることが特徴。ビームを3分割してトラッキング・エラー信号を検出する3ビーム法に比べて光の利用効率が高い。このため，できるだけ多くの光出力を確保することが必要な記録型の光ディスク装置などに向く。

†DPD (differential phase detection) 方式＝DVD-ROMのような再生専用ディスクに対してよく使われるトラッキング・エラーの検出方式。レーザ・ビームがピット列の左側にズレているか，右側にズレているかで回折パターンが変わることを利用し，ズレ量を求める。なお，ピットの深さがλ/4（λ：波長）の場合にトラッキング・エラー信号が最大になる。PP方式などに比べてピットの深さのバラつきによる影響を受けにくいなどの特徴がある。

大容量化のカギを握る 0.1mmカバー層方式

策定を終えたBD-RE規格は，全体を3つの技術に分けると理解しやすい。①ディスク構造や光学系の構成，信号処理技術などを規定する物理層の技術，②ディスクに対するアクセス方法などを規定するファイル・システム層と，ユーザーに提供する機能などを規定するアプリケーション層の技術，③コンテンツを守る著作権保護技術，である。ここからは，それぞれの技術について順に解説し，BD-RE規格の実体を明らかにしたい（表1）。

チルト・マージンをDVDと同等に

BD-REでは，DVDの5倍という面記録密度を実現するために，光ディスクの基本的なパラメータを一から見直した。すなわちレーザ光のビーム・スポット径を絞るために，光源波長λを短くし，対物レンズの開口数NA（numerical aperture）を高めた。一般にビーム・スポット径はλに比例しNAに反比例する。今回は両方を変えることで，一気にビーム・スポット径を縮小した。

具体的には，光源に波長405nmの青紫色レーザを採用した[注1]。現行DVDの650nmに対して約4割減である。一方，対物レンズのNAはDVDの0.6から0.85に増やした[注2〜3]。これらの変更により，ビーム・スポットの面積をDVDのものに比べて約1/5に縮めた。つまり，DVDに比べて5倍の面記録密度で記録マークを読み書きできる。

ただし，この方法を採ると新たな課題が浮上する。NAを高めるにつれて，その3乗に反比例してディスクとレーザ光の光軸の傾きに許される角度誤差（チルト・マージン）が狭くなってしまうのだ。これは，ディスク製造や装置の組み立てに許される機械的な誤差が極端に小さくなることを意味する。そこで今回はチルト・マージンを広げるために，記録膜面を覆うカバー層を0.1mmまで薄くした（pp.36-37の「光透過層は薄くても問題ない，デフォーカスと誤り訂正は補完関係に」参照）。こうすることで，チルト・マージンは現行DVD並みの±0.75度を確保した。

現行DVDのディスク構造を断念

この結果，今回のディスク構造は現行DVDに比べて大きく異なることとなった（図5）。DVDでは厚さが0.6mmのディスク基板2枚を張り合わせている（以下，0.6mm基板張り合わせ方式）。これに対してBlu-ray Discは，厚さが1.1mmのディスク基板上に記録層を設け，0.1mmの透明なカバー層で覆う構造である（以下，0.1mmカバー層方式）。

もちろん当初は，現行DVDと同じ0.6mm基板張り合わせ方式も検討した。その方が，現行DVDとの互換性を確保しやすいからだ。しかし，最終的に同構造を採ることは難しい

ライト・ストラテジー＝1つの記録マークを書き込むとき，その形状が歪まないように，半導体レーザを駆動する電流波形をパルス状に変化させる。この波形パターンをライト・ストラテジと呼ぶ。パルスの振幅や周期を変えることで記録マークを所望の長さにしたり，途中部がトラックの幅方向に広がってしまうのを防ぐ。ライト・ストラテジは一般に，媒体の記録膜や記録速度により異なる。

†OPC（optimum power control）＝記録膜の感度や半導体レーザごとの波長バラつきによる記録状態の違いを補正するためにレーザの光出力を調整すること。媒体の試し書き領域を使って適切な値を自動判断する。

注5）光ディスクの回転速度の限界を仮に1万rpmほどとすると，ディスク最外周における線速度は12倍速付近に達する。このときのデータ転送速度は，Blu-ray Discの面記録密度だと約400Mビット/秒になり，ハード・ディスク装置に匹敵する水準になる。

注6）Blu-ray Discのさらに次世代を担う光ディスク規格では，数百Gバイトの容量が期待されるだろう。その際はBlu-ray Discの技術をベースとして，多値記録や多層記録，新しい信号処理といったハードウエアによる大容量化と，符号化技術などソフトウエアによる大容量化の両面で容量拡大を模索していく必要がある。

表1 「BD-RE Ver.1.0」の主な仕様

片面単層の記録容量（片面2層媒体の場合）	23.3Gバイト（46.6Gバイト）	25Gバイト（50Gバイト）	27Gバイト（54Gバイト）
光源の標準発振波長	405nm		
ディスク直径	12cm（内径15mm）		
ディスクの厚さ	1.2mm		
記録膜を覆うカバー層の厚さ	0.1mm		
対物レンズの開口数	0.85		
トラック・ピッチ	0.32μm		
記録膜	Ge-Sb-Te系や共晶系などの相変化記録膜		
最短記録マーク長	0.16μm	0.149μm	0.138μm
面記録密度	16.8Gビット/(インチ)²	18Gビット/(インチ)²	19.5Gビット/(インチ)²
回転制御方式	CLV		
標準のデータ転送速度	36Mビット/秒		
記録トラック方式	グルーブ記録		
アドレス方式	ウォブル方式*1		
記録符号化方式	1-7PP*2		
誤り訂正方式	LDCとBISを組み合わせる方式		
映像記録方式	MPEG-2トランスポート・ストリーム		
音声符号化方式	DolbyDigital、MPEG-1 LayerⅡなど		

*1 松下電器産業が提案した「STW」方式と，ソニーが提案した「MSK」方式を組み合わせた方式。
*2 （1，7）RLL符号を改良したParity Preserve/Prohibit RMTR（repeated minimum transition run/length）の略。ソニーが提案した。
BIS：burst indicating subcode　CLV：constant linear velocity
LDC：long distance code　MSK：minimum shift keying　STW：saw tooth wobble

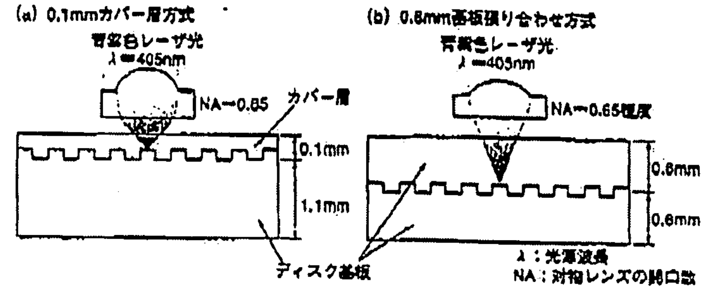

図5 厚さ0.1mmのカバー層を採用
DVDの次世代光ディスクを開発するに当たって，主に2種類の光学系を検討した。1つは，厚さ1.1mmのディスク基板上に記録層を設け，厚さ0.1mmのカバー層で覆う方式（a）。開口数（NA）が0.85と高い対物レンズでデータを読み出す。もう1つはDVDと同じく，厚さ0.6mmのディスク基板を張り合わせる方式である（b）。対物レンズのNAは0.65程度になる。Blu-ray Discでは0.1mmカバー層方式を採用した。

と判断した。理由は次の通りだ。

まず第1に，記録容量を20Gバイト以上に高めるのが難しい。現行DVDと同じ構造で単に光源波長を短波長化しただけでは，記録容量を12Gバイト程度までしか高められない[注10]。記録マークの間隔を詰める一方でデータを的確に読み取るためにPRML（partial response maximum likelihood）技術を導入する手法も試みたが，所望の記録容量には到達できなかった。

面記録密度を高める方法には，ディスクに形成したトラックの凸部と凹部の両方に記録する，いわゆる「ランド・グルーブ記録」を使う方法もある。この方法で隣り合うトラック間のクロストークを抑えながら，トラック・ピッチを詰める手法も検討した。しかし，レーザ光のビーム・スポット径が小さくなっても熱が伝播する範囲はそれほど狭まらない。従ってトラック・ピッチを縮めた分，隣接トラックへの熱伝播の影響は大きくなる。この結果，記録時に隣接トラックのデータを消してしまうという問題（クロスイレーズ）が起こり，これを克服できなかった。

片面2層ディスクを使ってこの壁を乗り越えようと考えたが，0.6mm張り合わせ方式だと，この手法を採用することも難しいと判断した。現行DVDとほぼ同じNAが0.6程度の対物レンズで絞ったビーム・スポットのパワー密度は，NA0.85の場合の半分近くまで低下してしまう。ビーム・スポットの面積が約2倍に広がるためだ。現在，BD-REで片面2層ディスクに記録するためにパルス発振で約50mWの光出力が必要になることを考えれば，0.6mm基板張り合わせ方式では100mWを超える青紫色半導体レーザが必要になる。これは現時点では手に入らない。

確かに光ディスク関連の学会では，0.6mm基板張り合わせ方式とNAが0.65の対物レンズ，PRML処理などを組み合わせて記録容量を20Gバイトまで高めた成果も報告されている[1]。しかしこの場合，前述のチルト・マージンが±0.3度程度と現行DVDの半分近くまで狭くなってしまう。ここまで狭いと，このディスクと光軸の傾きを補正する機構（チルト・サーボ）を光ピックアップに追加する必要がある。ただし，ディスクが変形している場合は，回転に同期してこの傾き量も変動する。これに高速に追従できる機構を光ピックアップに実装するのは難しい。動的に正確なチルト角を検出するのにも限界がある。このため，0.6mm基板張り合わせ方式の採用は事実上，困難だと考えた。残る選択肢の中で最も有望なのが0.1mmカバー層方式だった。

1レンズで互換性確保が可能に

BD-RE規格の録画機を製品化する場合，

注7) 青紫色レーザの光源波長である405nmより短波長の光源（紫外線レーザ）も検討したことがある。しかし，400nmより短い波長ではポリカーボネートなどの基板材料の吸収率が急増し，レーザ光が透過しにくくなる。さらに，紫外線の照射により樹脂材料が劣化する問題もある。

注8) 対物レンズの代表的な開口数（NA）は，CDの場合に0.45，DVDでは0.6だった。一般にNAが高いほどレンズの傾き度などに対する要求は厳しくなる。0.45と0.6は，その当時に量産が見えているレンズの中で最も高いNAの値だった。Blu-ray Discでは，レンズを2枚重ねてNAを0.85に高める方法を提案した。2枚のレンズはそれぞれDVDのレンズの製造技術があれば作ることができる。この2枚組レンズは，光学設計にもよるが，ディスクとレンズの間隔（WD：working distance）を0.14mm程度まで近づける必要がある。このためレンズとディスクの衝突を懸念する声が多い。WDが小さいと衝突の確率が高まることは否めないが，振動を検出して保護する回路を取り付けるなど万一に備えることは可能である。さらに最近では1枚のレンズでNAを0.85まで高めたレンズが開発されている。同レンズはWDが0.5mm程度と広いため，実用上問題はないだろう。

注9) 光源波長が短く，NAが大きい光学系を使うと，半導体レーザの光出力を抑えられるという利点がある。ビーム・スポット径を絞り込む分，レーザ光のエネルギーが集中するためだ。現行DVDの光学系である波長650nmの赤色レーザ光とNAが0.6の対物レンズの組み合わせと比べて，Blu-ray Discの波長405nmの青紫色レーザ光とNAが0.85の対物レンズの組み合わせでは，記録に必要な半導体レーザの光出力がおよそ1/4で済む。例えば，片面単層のBD-RE媒体に36Mビット/sの速度で記録する場合，記録層面上の最大光出力は5.2mW，片面2層媒体では10.4mWでよい。なお，図5の下部にCD，DVD，Blu-ray Discそれぞれのビーム・スポット径と強度分布を示した。

注10) 0.6mm基板張り合わせ方式を採用している現行の記録型DVDでは，チルト・サーボを用いてNAを0.65程度に高めている例がある。しかし，それ以上にNAを上げるのはチルト・サーボの性能上，難しい。一方，光源波長を短くしてもチルト・マージンは狭くなる。例えば光源波長を405nmに短波長化しながらチルト・マージンを維持しようとすると，短波長化による収差量の増分を打ち消すためにNAを0.65から0.55程度まで下げなければならない。NAが0.55まで下がると，結果的に実現できる記録容量は10Gバイト程度まで減少してしまう。

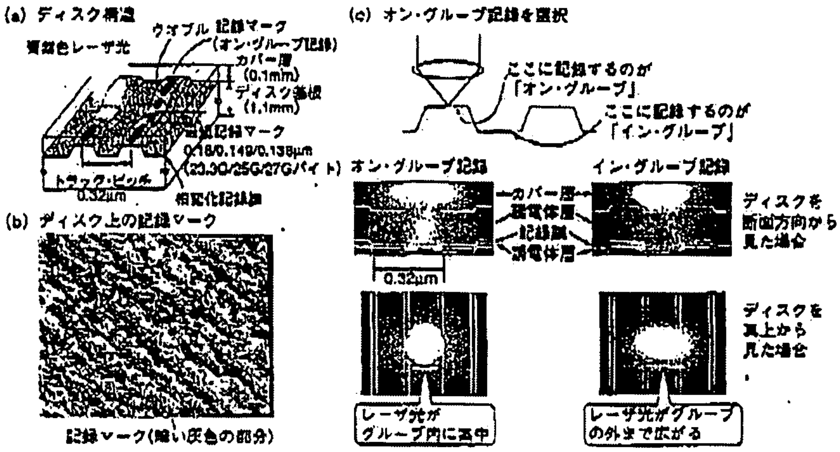

図6 「オン・グループ」にマークを記録
(a) にBlu-ray Discの書き換え可能な媒体のディスク構造を示した。ディスク上に刻んだ凹凸の一方のみにデータを記録する，いわゆるグループ記録を採用している。(b) は実際にマークを記録したディスクを真上から見た電子顕微鏡写真である。データは，青紫色レーザ光源の入射方向から見た場合の凸部（オン・グループ）に記録する (c)。数値計算によるシミュレーションの結果，オン・グループ記録ではレーザ・ビームがグループ内に集中するのに対し，凹部（イン・グループ）の場合はグループの外側まで広がることが分かった。

少なくとも現行DVD媒体との再生互換性を確保することが必要になるだろう。このとき0.1mmカバー層方式ではディスク構造や対物レンズなどの光学系が大きく変わるため，互換性の確保が難しいと指摘する声がある。しかし，この課題解決にはメドが付いている。

最も確実な方法は，それぞれの対物レンズを別に用意して切り替える方法である。しかし，こうすると光学部品の数は多くなってしまう。このため，DVDとBD-RE媒体で1つのレンズを共有する技術開発も進んでいる。これは，DVDの赤色半導体レーザ光とBD-REで使う青紫色半導体レーザの波長の違いを利用してNAやカバー層の厚さの違いを吸収しようというものだ[注11]。既に複数メーカーがこうした技術の開発を発表しており，展示会などでデモンストレーションを行った例も出てきている。

実は，DVDが登場したときも同じ課題を抱えていた。CDに対して光源波長を短くし，対物レンズのNAを増やし，ディスク基板の厚さを1.1mmから0.6mmに減らしたからだ。このときも当初は，対物レンズを切り替えていた。しかし今では1レンズで共有する方式が当たり前である。現在のDVD装置には，CD-Rの再生に向けた赤外半導体レーザとDVD再生用の赤色半導体レーザが搭載されており，光源波長の違いを利用してNAやディスク基板の厚さを切り替えている[注12]。技術のハードルの高さに違いはあるが，1レンズでBD-REとDVDに対応する録画機が登場するのも時間の問題だろう。

トラック構造/信号処理技術の「いいとこ取り」を実現

BD-REのディスク構造の特徴は0.1mmカバー層方式だけではない。記録型DVDの技術開発で培った経験が散りばめられている。具体的には今回，DVD-RWやDVD-RAM，DVD+RWから優れた特徴を抽出してBD-RE規格向けに改良し，採用している[注13]。

まずDVD-RWからは，ディスクに刻み込まれたトラックの溝に記録する，いわゆる「グループ記録」を継承した（図6）[注14]。グループ記録を採用した理由は，現在策定中のBD-ROMやBD-Rとの再生互換性を確保するためだ。ランド・グループ記録を採用して

注11）Blu-ray Disc普及編において，DVDとの再生互換性を確保するためには，赤色半導体レーザの搭載は必須となる。同レーザを搭載しないと，片面2層の再生専用DVDディスクが読めないからだ。片面2層ディスクは，レーザ光の入射方向から見て手前の記録層の反射膜としてAuやSiを使っている。これらは波長選択性が極めて強い。Auは青紫色レーザ光を吸収するため，奥側の記録層が読めなくなる。Siは青紫色レーザ光をほとんど反射しないため，手前の記録層が読めなくなる。

注12）CDを再生する場合，赤外レーザ光は対物レンズの中央付近のNAが低い部分だけを選択的に通るようにする。さらに，波長依存性の強い光学素子を挿入してディスク基板の厚さの違いを吸収している。

注13）一般に光ディスクの規格策定は再生専用ディスクから始まる。このため，その後から規格を策定することになる記録型媒体は，再生専用規格との互換性に気を配りながら規格を定めてきた。今回は書き換え可能な媒体規格から策定した結果，こうした制約に縛られずに済んだ。こうした状況が「いいとこ取り」の規格を生んだといえる。

注14）書き込み可能な光ディスクの記録トラック方式は主に2種類ある。ディスクに形成したトラックの凸部と凹部のいずれか一方だけに記録する「グループ」記録と，両方に記録する「ランド・グループ記録」である。現行の光ディスクではCD-R/RW，DVD-R/-RW，DVD+R/+RWなどがグループ記録を採用する。グループ記録は，さらに2つに分けられる。レーザ光の入射方向から見て凸側のトラックに書き込む「オン・グループ記録」と凹側に書き込む「イン・グループ記録」である。CDやDVD系の記録型光ディスクではずっとイン・グループ記録を採用してきたが，今回のBD-RE規格ではオン・グループ記録を採る。これはシミュレーション結果や実験結果から導き出した。例えば図6 (c) に示すシミュレーション結果では，オン・グループ記録の方が，レーザ・ビームがグループ内に集中していることが分かる。トラック・ピッチは0.32μm（溝幅0.16μm）とした。一方のランド・グループ記録はDVD-RAMなどが採用する。同じトラック・ピッチ（または面記録密度）の場合，トラックの幅をグループ記録の2倍近くに広げられるのが特徴だ。

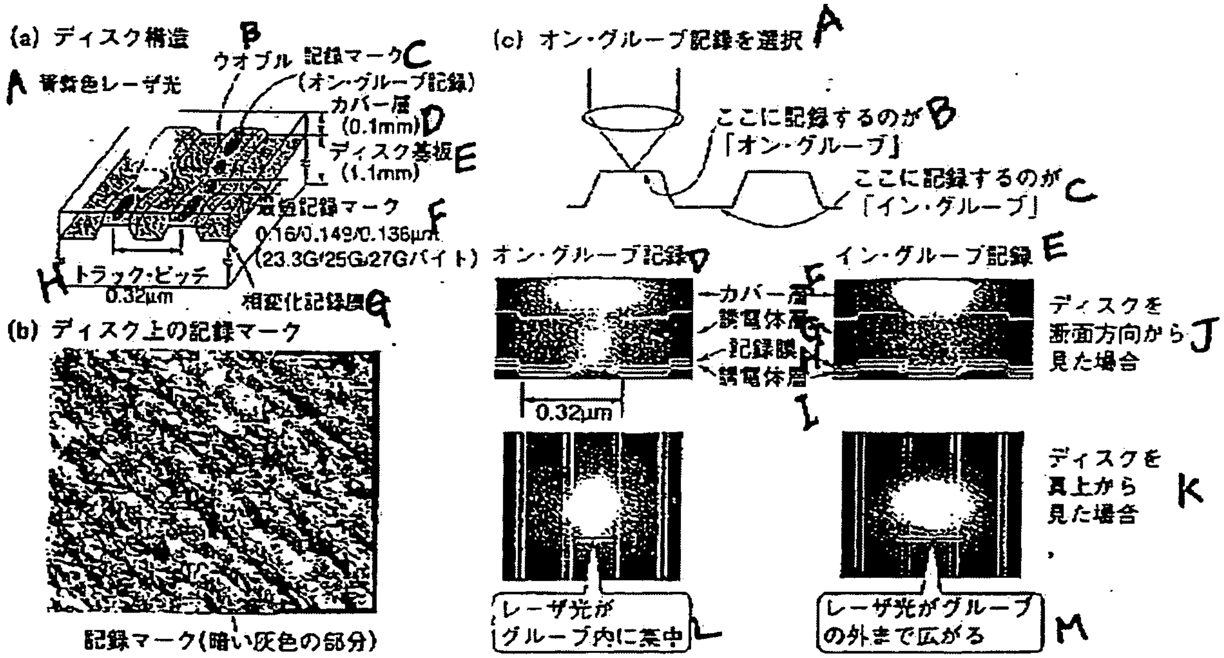

図6 「オン・グルーブ」にマークを記録
(a) にBlu-ray Discの書き換え可能な媒体のディスク構造を示した。ディスク上に刻んだ凹凸の一方のみにデータを記録する，いわゆるグルーブ記録を採用している。(b) は実際にマークを記録したディスクを真上から見た電子顕微鏡写真である。データは，青紫色レーザ光源の入射方向から見た場合の凸部（オン・グルーブ）に記録する (c)。数値計算によるシミュレーションの結果，オン・グルーブ記録ではレーザ・ビームがグルーブ内に集中するのに対し，凹部（イン・グルーブ）の場合はグルーブの外側まで広がることが分かった。

少なくとも現行DVD媒体との再生互換性を確保することが必要になるだろう。このときが当たり前である。現在のDVD装置には，CD-Rの再生に向けた赤外半導体レーザと

注11) Blu-ray Disc録画機において，DVDとの再生互換性を確保するためには，赤色半導体レーザの搭載は必須となる。同レーザを搭載しないと，片面2層の再生専用DVDディスクが読めないからだ。片面2層ディスクは，レーザ光の入射方向から見て手前の記録層の反射膜としてAuやSiを使っている。これらは波長選択性が極めて強い。Auは青紫色レーザ光を吸収するため，奥側の記録層が読めなくなる。Siは青紫色レーザ光をほとんど反射しないため，手前の記録層が読めなくなる。

注12) CDを再生する場合，赤外レーザ光は対物レンズの中央付近のNAが低い部分だけを選択的に通るようにする。さらに，波長依存性の強い光学素子を挿入してディスク基板の厚さの違いを吸収している。

Table 1 (Major specs for BD-RE Ver. 1.0)

Storage Capacity for Single-sided, Single Layer (Two layers on each side)	23.3 Gb (46.6 Gb)	25 Gb (50 Gb)	27 Gb (54 Gb)
Wavelength of Standard Oscillation of Light Source		405 nm	
Diameter of Disc	12 cm (internal diameter 15 mm)		
Thickness of Disc		1.2 mm	
Thickness of Cover Layer for Recording Layer		0.1 mm	
Aperture of Objective Lens		0.85	
Track Pitch		0.32 μm	
Recording Film	Phase change recording film (ex. Ge-Sb-Te or eutectic)		
Minimum Recording Mark Length	0.16μm	0.149μm	0.138μm
Surface Recording Density (Gb/inch^2)	16.8	18	19.5
Rotation Control		CLV	
Standard Data Transfer Rate		36 Mb/second	
Recording Track		Groove Recording	
Address		Wobbling*1	
Encoding		1-7PP*2	
Error Correction		Combination of LDC and BIS	
Image Recording		MPEG-2 Transport Stream	
Sound Encoding		DolbyDigital, MPEG-1 Layer II, etc.	

*1 Combination of "STW" proposed by Matsushita and "MSK" by Sony.

*2 Abbreviation for "Parity Preserve/Prohibit RMTR (repeated minimum transition runlength)," a modification to (1,7)RLL proposed by Sony.

BIS: burst indicating subcode

CLV: constant linear velocity

LDC: long distance code

MSK: minimum shift keying

STW: saw tooth whole

Fig. 6

(a) shows the structure of a rewriteable Blu-ray disc. The disc employs "groove recording" where data is recorded either on the land or the groove on the disc. (b) is an electron microscope image looking straight down on recorded marks. Data is recorded on the groove (on-groove) as seen from the direction of incident light from a blue-violet laser device (see (c)). A numerical simulation demonstrated that the laser beam concentrated in grooves in on-groove recording and expands beyond grooves in in-groove recording.

(a) Disc structure

A: Blue-violet laser beam

B: Wobble

C: Recording mark (on-groove recording)

D: Cover layer (0.1 mm)

E: Disc substrate (1.1 mm)

F: Minimum recording mark

0.16/0.149/0.138 μm for 23.3/25/27 Gb

G: Phase change recording film

H: Track pitch

(b) Recording marks (appearing dark gray) on disc

(c) A: On-groove recording selected

B: Data is recorded here in on-groove recording.

C: Data is recorded here in in-groove recording.

D: On-groove recording

E: In-groove recording

F: Cover layer

G: Dielectric layer

H: Recording layer

I: Dielectric layer

J: Disc as seen from cross-sectional direction

K: Disc as seen from above

L: Laser beam concentrates in grooves

M: Laser beam expands beyond grooves

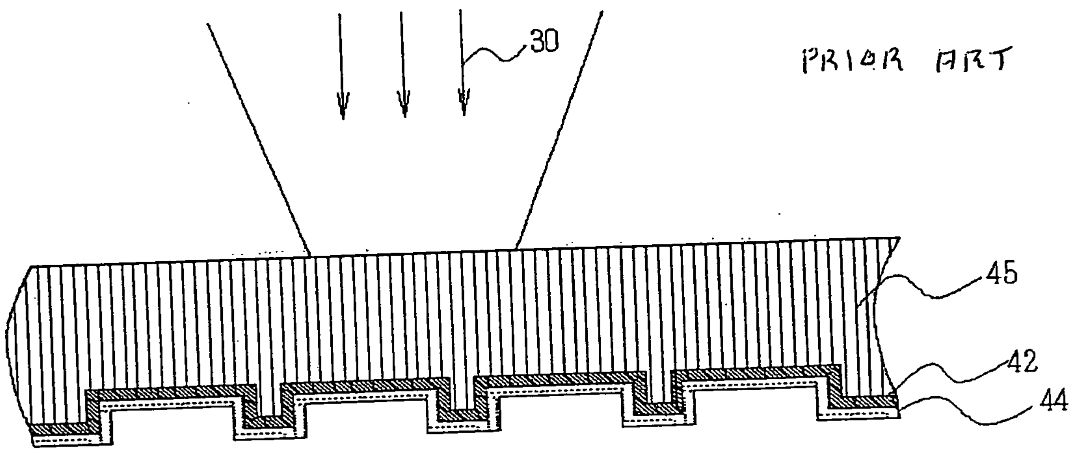

Fig.7

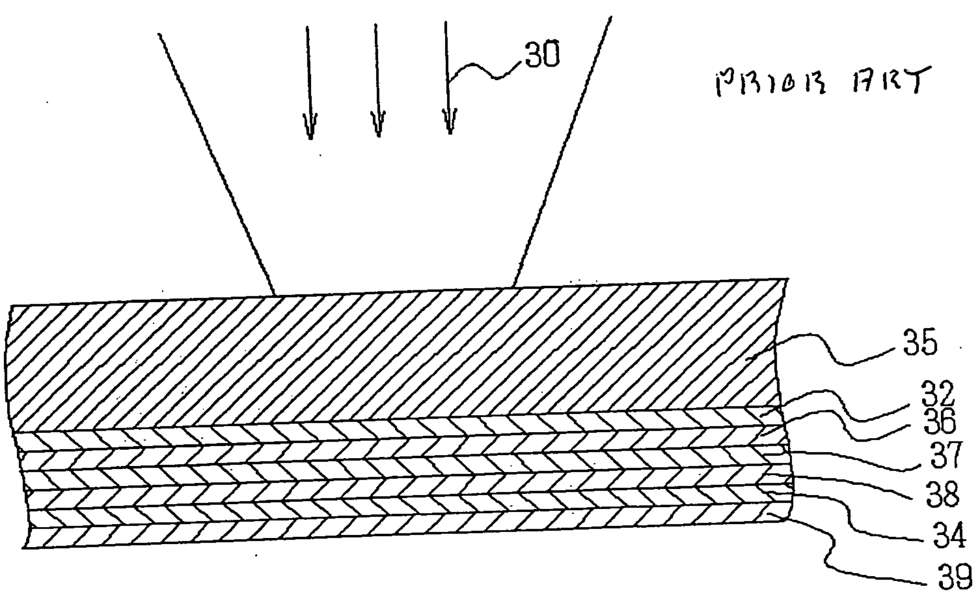

Fig.8